Year: 2005

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Originally published at:
Huber, Silvia; Kneubühler, Mathias; Zimmermann, Niklaus E; Itten, Klaus I (2005). Potential of spectral feature analysis to estimate nitrogen concentration in mixed canopies. In: 4th EARsel workshop on Imaging Spectroscopy, Warsaw, Poland, 27 April 2005 - 30 April 2005. s.n., 219-226.

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POTENTIAL OF SPECTRAL FEATURE ANALYSIS TO ESTIMATE NITROGEN CONCENTRATION IN MIXED CANOPIES

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ABSTRACT

Leaf nitrogen content is of great interest because of its role in photosynthesis, ecosystem productivity and thus influences global cycling of carbon and oxygen. The nitrogen concentration of a mixed forest in Switzerland was explored using HyMap data. The imaging spectrometer data were processed to correct for atmospheric and geometric distortion. In this preliminary study the spectral data was investigated using continuum removal analysis. In order to reduce external influences a normalization procedure was used. Relationships between transformed reflectance and field-measured nitrogen concentration were investigated by using correlograms. A backward stepwise linear regression routine was applied to select the most important bands in predicting the response variable. This preliminary study showed that continuum removal analysis is applicable on HyMap data in complex mixed forests. Differences among plant functional types as well as species are visible in the normalized band depths curves. Correlations between transformed HyMap spectral data and measured nitrogen concentration could be found.

INTRODUCTION

Many biochemical processes, such as photosynthesis, respiration, evapotranspiration and decomposition are related to the foliar concentration of biochemicals like chlorophyll, water, nitrogen, lignin and cellulose [1]. These measures provide indicators of plant productivity, decay rate of leaf litter and availability of nutrients in space and time [2]. Accurate remotely sensed estimates of foliar biochemical concentration of vegetation canopies can provide a valuable aid to the understanding of ecosystem functioning over a wide range of scales [3]. Leaf nitrogen content is of great interest because of its role in photosynthesis, ecosystem productivity and thus influences global cycling of carbon and oxygen [4, 5]. Canopy nitrogen concentrations showed a strong linear correlation with soil carbon to nitrogen (C:N) ratios [6]. They were also related to both net nitrogen mineralization and nitrification. Nitrogen content in litter influences the lignin decomposition rate strongly [7] and ecosystem models can be improved with spatial information of nitrogen concentration [8]. Therefore we carried out this preliminary study to investigate the potential of continuum removal analysis in characterizing nitrogen concentration in complex forest canopies. Transformed continuum-removed reflectance spectra of dried and ground leaves showed good results for estimating the concentration of biochemicals [2, 9]. The possibility of establishing a single equation capable of estimating the chemical concentrations in a wide variety of species from the reflectance spectra of dried leaves was demonstrated [9]. The advantage of continuum removal and band normalization in reducing the impact of extraneous influences such as atmospheric effects or soil background is specially important for investigations with remotely sensed data. Another difficulty is the masking of absorption features by leaf water. Water accounts for up to 80 per cent of fresh weight of green leaves [4]. The extension from controlled laboratory conditions to field level has been successful in grasslands [10] as well as in eucalypt stands [11]. Since it was shown to make visible subtle spectral differences among different conifer types [12], we decided to test the method in a more complex mixed forest, a stand containing conifers and broad-leaved species.

METHODS

Study area

The data used in this study were collected in a mixed forest near the village of Vordemwald, which lies in the Swiss Plateau region. Six study plots were located at the site to cover a wide range of species. The broad-leaved stands are composed mainly of European beech (*Fagus sylvatica* L.), English oak (*Quercus robur* L.), European ash (*Fraxinus excelsior* L.), the coniferous stands of silver fir (*Abies alba*) and Norway spruce (*Picea abies* L.). The sampling was accomplished in mixed woods to consider the complexity of a natural ecosystem. A long-term research plot (termed LWF) run by the Swiss Federal Institute of Forest, Snow and Landscape Research (WSL) is situated at the test site, which guarantees a monitoring in the future.

Field sample collection

Field data were collected to quantify the nitrogen concentration among the tree species in order to calibrate and validate the results of the HyMap analysis. To analyze biochemical composition in the laboratory, foliar material was sampled in late July to coincide with the peak of the growing season and with the overflights of the HyMap instrument. A tree climber excised branches at the top of the crown. To retrieve a statistically representative sample, each sample consisted of several leaves from three different branches while needle samples contained the first three needle years. A high-temperature, dry combustion method was applied to retrieve the nitrogen concentration using a Carlo Erba Elemental Analyzer. The position of each sampled tree was determined with a Trimble GeoXT receiver. Postprocessing differential correction was applied on the data, carried out by the GPS Pathfinder Office software.

Remote sensing data

Imaging spectrometer data were obtained for the study area, using HyVista's Hyperspectral Mapping Imaging Spectrometer (HyMap). The HyMap instrument is flown on a Dornier Do 228 aircraft at an altitude of 3000 m asl and measures upwelling radiance from the solar reflected spectrum in 126 channels from 0.45 to 2.48 µm, with a spectral resolution of 15-20 nm. On 29 July 2004, we obtained three 2.5x12 km scenes with a spatial resolution of 5 m covering the study site Vordemwald under cloud free conditions. HyMap at-sensor radiance data are transformed to apparent surface reflectance using the ATCOR4 software [13]. ATCOR4 performs a combined atmospheric/topographic correction, where effects of terrain such as slope, aspect and elevation of the observed surface is accounted for. The imaging spectrometer data is orthorectified based on the parametric geocoding procedure PARGE, which considers the terrain geometry and allows for the correction of attitude and flightpath dependent distortions [14]. Orthorectified imagery is a prerequisite for the subsequent radiometric correction and is necessary for the final quantitative exploitation of the data. After calibration has produced a measure of surface reflectance, the data were compared to ASD field spectra. Land cover types were assessed with ASD transect-measurements parallel to the HyMap overflights to meet identical illumination conditions. For further analysis the spectral value of one pixel for each sample tree was extracted from the HyMap data.

Spectral transformation methods

In this preliminary study we used continuum removal analysis as spectral transformation method. This approach enables the isolation of absorption features of interest, thus increasing the coefficients of determination and facilitating the identification of more sensible absorption features. By isolating the spectral features, removing the continuum and scaling the band depth to be equal, subtle band shifts and shapes can be seen [15]. The continuum is simply an estimate of the other absorptions present in the spectrum, not including the one of interest [16]. Five wavelength ranges have been selected according to known nitrogen absorption features (Tab. 1) [2]. Straight-line segments were used to approximate the continuum lines (Fig. 1) [16].

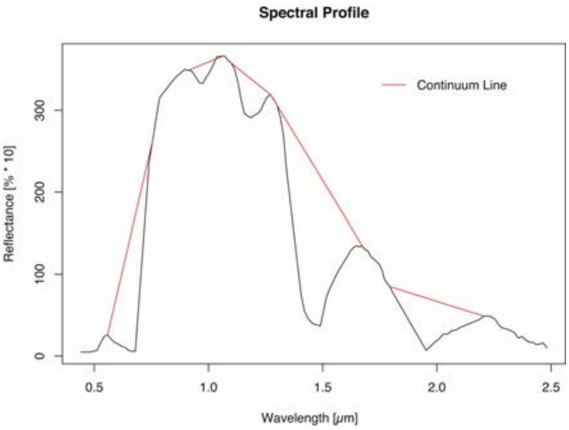


Figure 1: Linear segments used to isolate each nitrogen absorption feature in HyMap reflectance spectrum.

Once the continuum lines are established for the predefined wavelengths, the continuum-removed spectra are calculated by dividing the original reflectance values by the corresponding values of the continuum line [9]. In order to minimize external influences we normalized band depths calculated from the continuum-removed reflectance spectra. The normalized band depths (BNC) within the continuum-removed absorption band are calculated by dividing the band depth of each channel by the band depth at the band center (Eq. 1):

$$BNC = \left(1-\left(R/R_i\right)\right)/\left(1-\left(R_c/R_{ic}\right)\right), \tag{1}$$

where R is the reflectance of the sample at the waveband of interest, R_i is the reflectance of the continuum line at the waveband of interest, R_c is the reflectance of the sample at the absorption feature center and R_{ic} is the reflectance of the continuum line at the absorption feature center. The band center is the minimum of the continuum-removed absorption feature [9]. Afterwards, BNC values are correlated with measured leaf nitrogen concentration.

Table 4: Preselected wavelength ranges and their associated absorption features for nitrogen [2]. The first column assigns a feature number to the wavelength ranges.

Feature No.	Selected wavelength ranges [nm]	Known nitrogen absorption features [nm]
1	558-755	640, 660
2	912-1069	910,1020
3	1273-1673	1510
4	1794-2205	1940, 1980, 2060, 2130-2180
5	2223-2420	2240, 2300, 2350

Statistical analysis

Relationships between BNC values in the selected wavelength ranges and field-measured nitrogen concentration were investigated in order to find suitable wavelengths correlated with nitrogen concentration. By using correlograms wavelengths were identified and a backward stepwise linear regression routine was applied to reduce the number of chosen bands to avoid overfitting. Stepwise regression fits an observed dependent data set using a linear combination of independent variables, in this case BNC values at discrete wavelengths. The statistical methods were implemented by *R*, which is a free software environment for statistical computing and graphics [17]. The result of this statistical method was a number of wavelengths correlated with the dependent variable and a linear equation combining the values of the independent data set at these wavelengths with coefficients established by the regression [9]. The statistical results were assessed in terms of the adjusted coefficient of determination R^2, which accounts for the number of predictors.

PRELIMINARY RESULTS

Foliar nitrogen concentration

Foliar nitrogen concentration, as measured in the laboratory, varied more across deciduous than coniferous species. Foliar nitrogen concentration (percent by dry weight) ranged from 1.81 % to 2.75 % (n = 14, mean = 2.20 %) among deciduous species and from 1.00 % to 1.59 % (n = 22, mean = 1.17 %) among conifers (Fig. 2). A lower nitrogen concentration is characteristic for conifers compared to broad-leaved species.

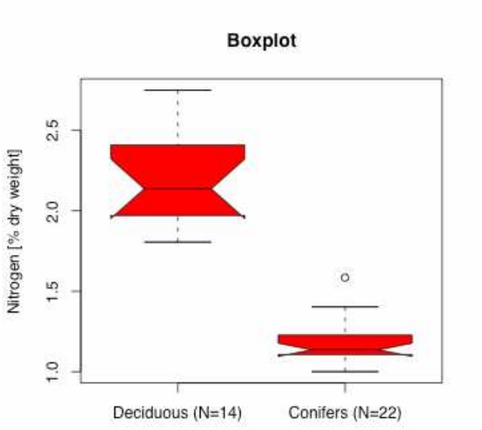
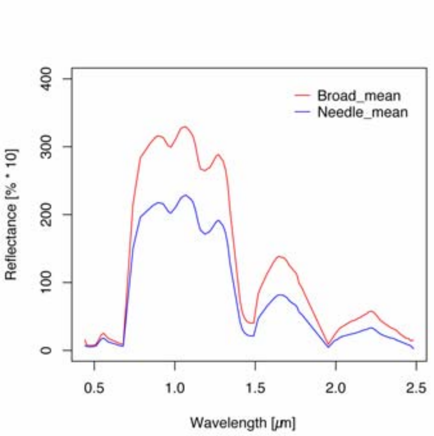


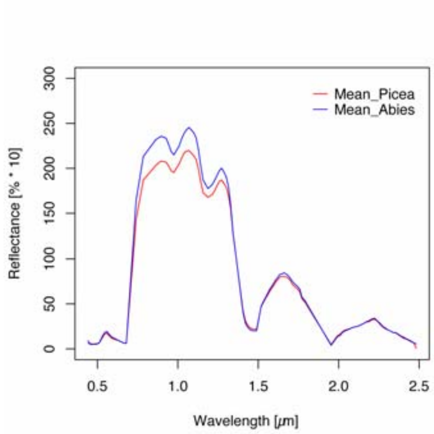
Figure 2: Distribution of foliar nitrogen concentration in percent by dry weight. Box plots indicate the median, quartile and range of measured foliar nitrogen concentration for deciduous and coniferous species.

Reflectance spectra

Mean reflectance spectra of conifers and deciduous species have distinctive different reflectance values in the near infrared (NIR) and shortwave-infrared (SWIR) region (Fig. 3a). The NIR region is mainly influenced by canopy water content and canopy structure, while in the SWIR region water causes the major absorption features. Evergreen conifer reflectance spectra have a low level of reflectance in the visible region (less than 5%) and a maximum in the NIR plateau (less than 25%). Reflectance spectra of deciduous species have a slightly higher reflectance in the visible part while the major difference occurs in the NIR-plateau region where the reflectance is partially more than 10 % higher. The silver fir and Norway spruce reflectance spectra are nearly identical except in the NIR plateau (Fig. 3b).



(a)



(b)

Figure 3: (a) HyMap mean reflectance spectra of conifers and deciduous tree types and (b) comparison between silver fir (Abies alba) and Norway spruce (Picea abies L.).

Continuum removal analysis

Normalized continuum-removed absorption features of two forest types are shown in (Fig. 4). In general, subtle differences are visible between the two functional types in the second (912-1069 nm) (Fig. 4a) and third (1273-1673 nm) nitrogen absorption feature. The reflectance spectra of conifers have a wider absorption feature at 1.51 µm compared to deciduous trees (Fig. 4b). The BNC spectra of the first (558-755 nm) and fourth (2223-2420 nm) selected range were nearly identical, whereas the fifth wavelength range (2223-2420 nm) had to be omitted for all analysis due to too much noise.

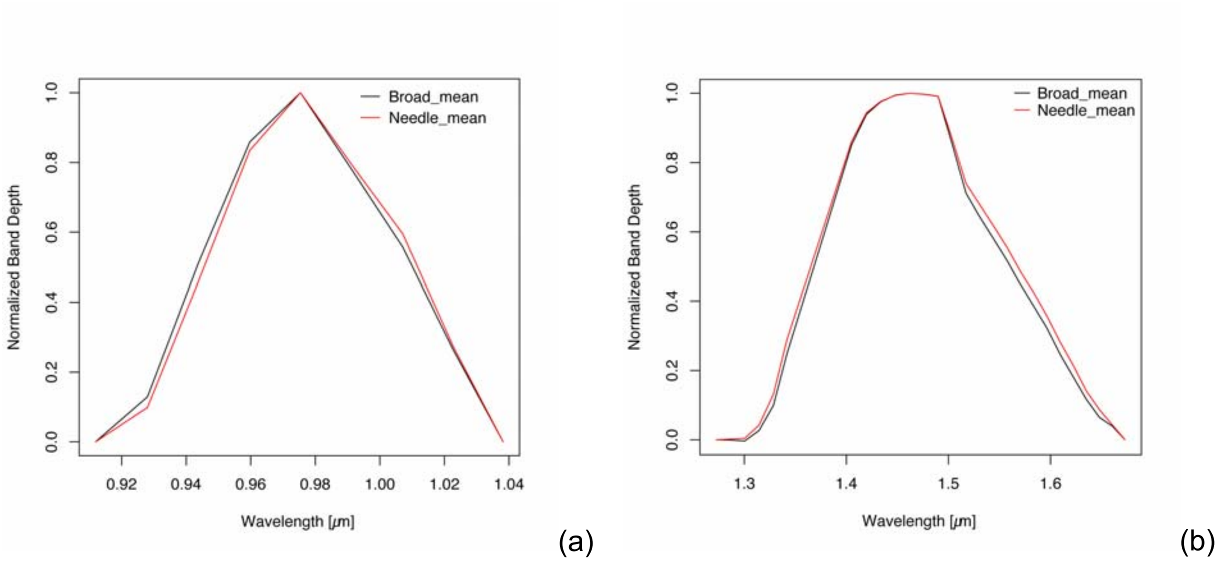


Figure 4. Comparison of normalized band depth of broad-leaved and needle-leaved tree species. Subtle spectral differences can be seen in the (a) second (912-1069 nm) and (b) third (1273-1673 nm) nitrogen absorption feature.

Major differences between continuum-removed, normalized spectra of Norway spruce and silver fir appear in the second absorption feature (912-1069 nm). The reflectance spectra of silver fir have an apparent wider absorption feature compared to Norway spruce (Fig. 5a). Subtle differences are also visible in the 1.98 µm absorption feature (Fig. 5b). The observable spectral differences between these two conifers suggest that imaging spectroscopy may discriminate conifer forest cover types based on subtle variations in their reflectance spectra [12].

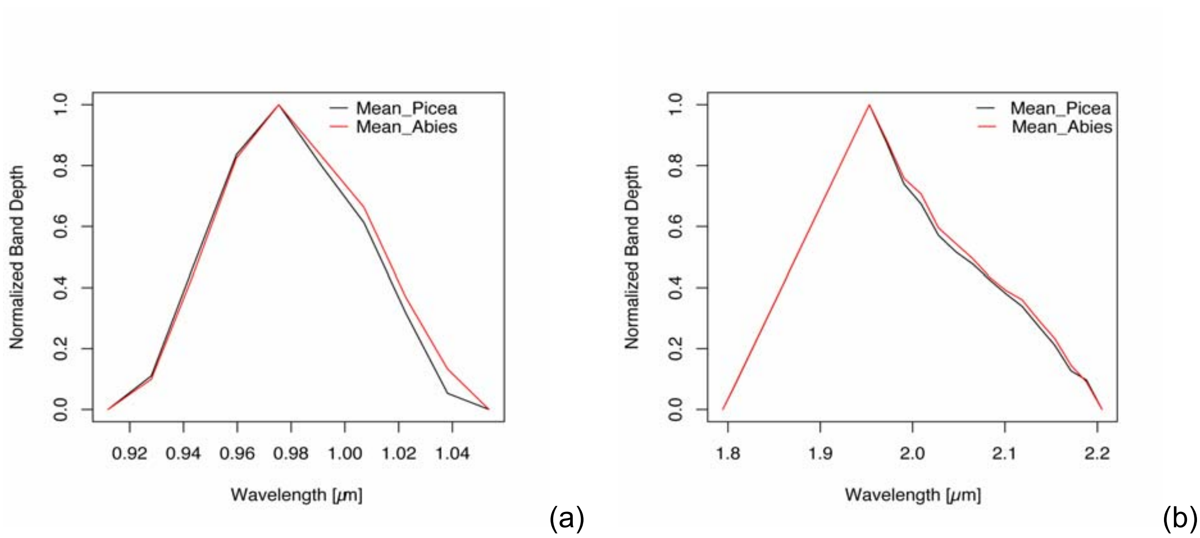


Figure 5: Comparison of normalized band depth of Norway spruce (Picea abies) and silver fir (Abies alba).

Correlating BNC values of deciduous species with measured nitrogen concentration assigned eight HyMap bands with a correlation coefficient higher than 0.4 (Fig. 6). Correlating needle-leaved samples resulted in lower correlation coefficients. Therefore the deciduous dataset was chosen for further analysis in this pilot study.

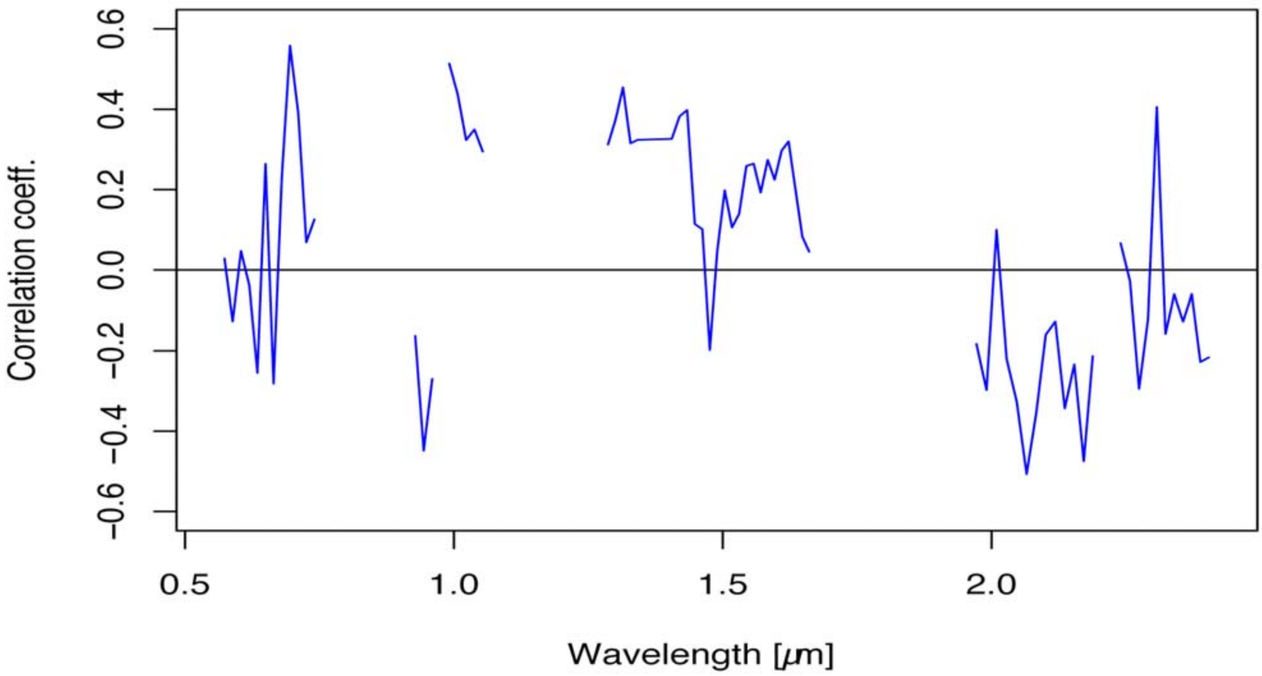


Figure 6: Correlogram on the deciduous spectra of the preselected wavelength ranges using normalized band depths (BNC).

After building a linear model with all eight possible explanatory variables, a backward stepwise regression procedure was applied. Four bands were found which are important in predicting the response variable. A first attempt of running a simple multiple linear regression with four selected bands resulted in an adjusted R^2 of 0.69. For significant results further analysis have to be considered.

CONCLUSIONS

In this study we applied an empirical method to estimate nitrogen concentration of deciduous and coniferous trees. In order to reduce external influences a normalization procedure was used. This study showed that continuum removal analysis is applicable on HyMap data in complex mixed forests. Differences among plant functional types as well as species are visible in the BNC curves. Problems can occur from positional errors due to inaccurate GPS recordings or spectral distortions in the HyMap data due to the large field of view of the sensor combined with the height of forest canopy. Consequently a very accurate geocorrection is important and a digital surface model is an advantage for the processing in PARGE. For better positional accuracy, GPS measurements should be done in winter for deciduous stands. Further, the pixel extraction method can certainly be improved by more sophisticated techniques, for example by applying geospatial statistics. The limitations of using stepwise multiple linear regression for developing calibration equations are known [18] and therefore another approach might be preferable. The developed equations have to be validated in other study sites and the number of investigated tree species must be increased.

For that reason the number of samples must also be increased for retrieving statistically significant results.

ACKNOWLEDGEMENTS

The authors would like to thank the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), DLR for scheduling the flight campaign and the Swiss National Science Foundation. We also thank the many individuals who have helped with data collection and analysis.

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